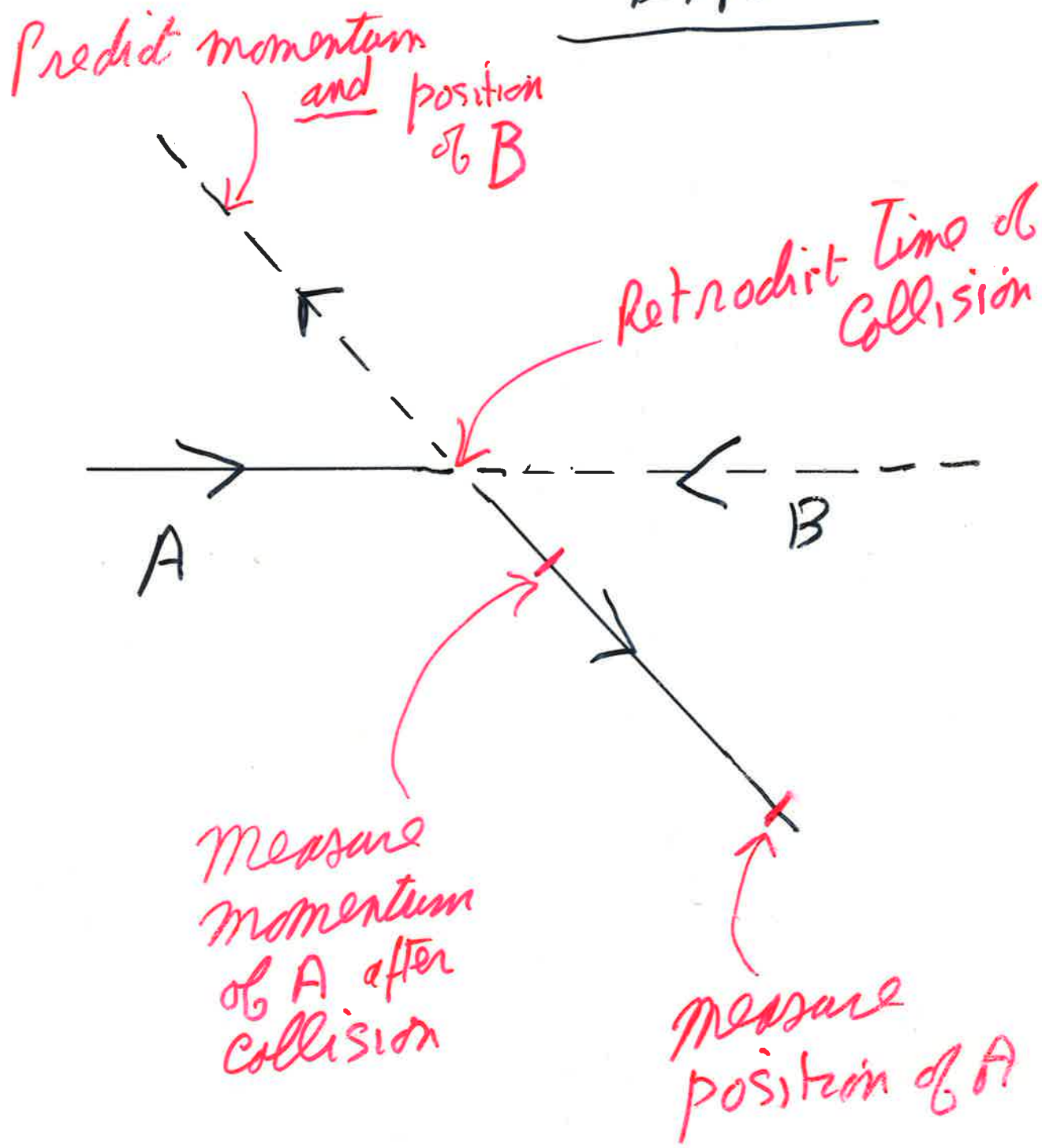
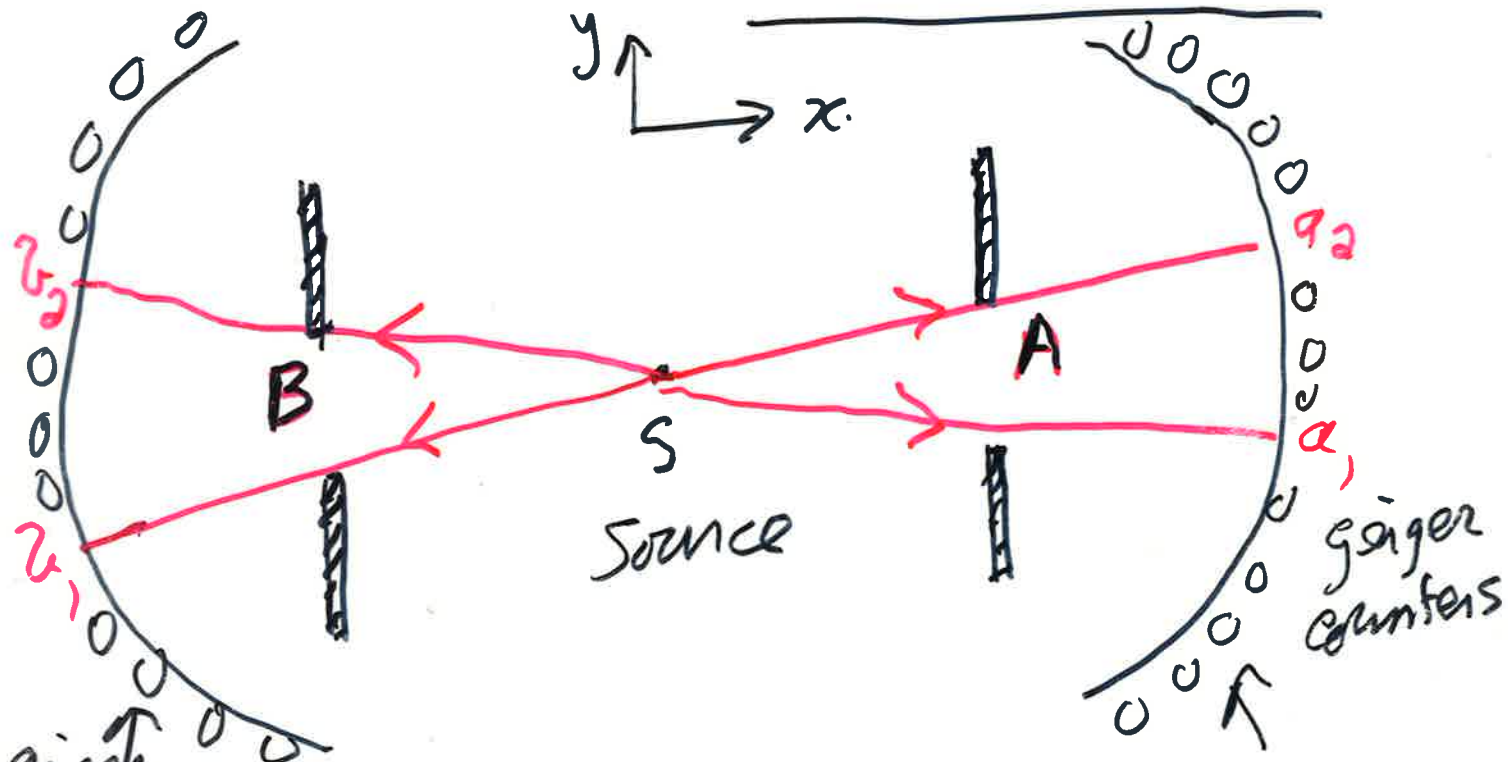
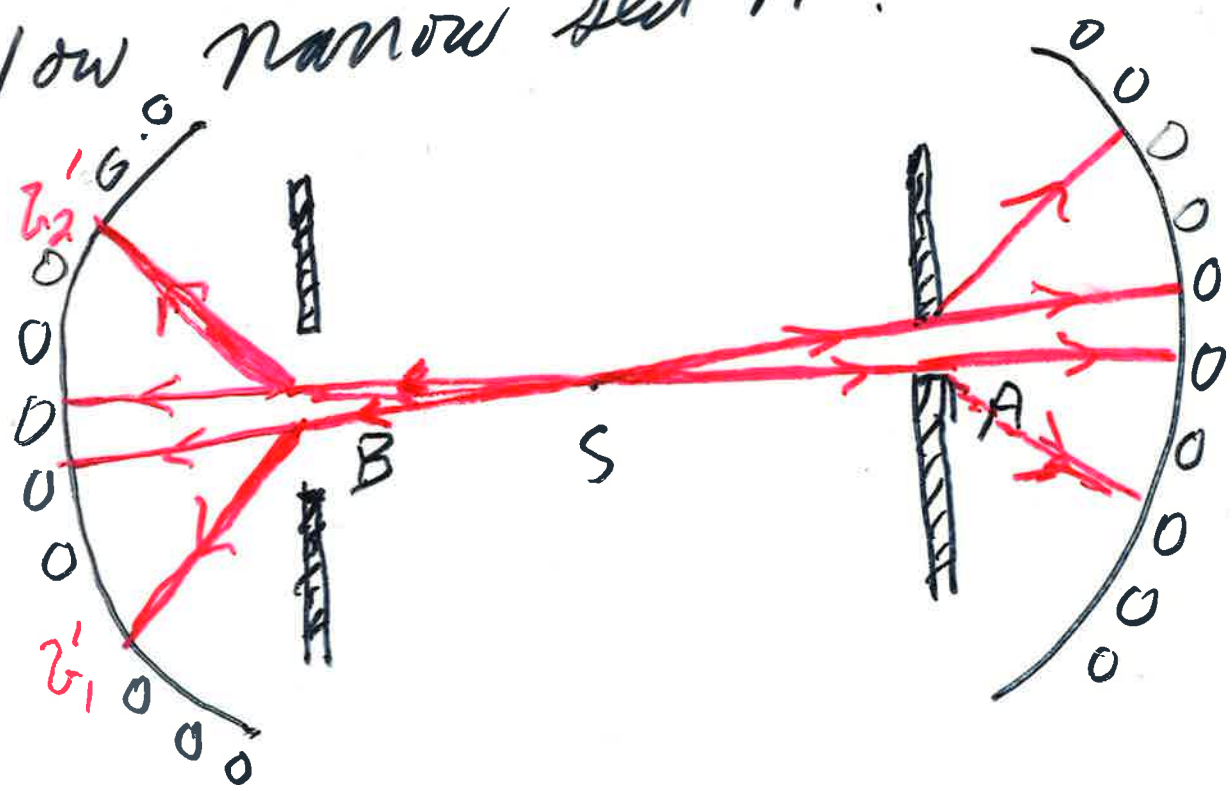
Popper's 1934 Thought Experiment



Popper's 1982 Thought Experiment



Now narrow slit A:



The EPR Source

$$\Psi_0 = \int_{-\infty}^{+\infty} |y\rangle \otimes |y\rangle \, dy$$

$$= \int_{-\infty}^{+\infty} |p_y\rangle \otimes |-p_y\rangle \, dp_y$$

So the EPR source is an infinite <u>incoherent</u> line source.

Why incoherent?

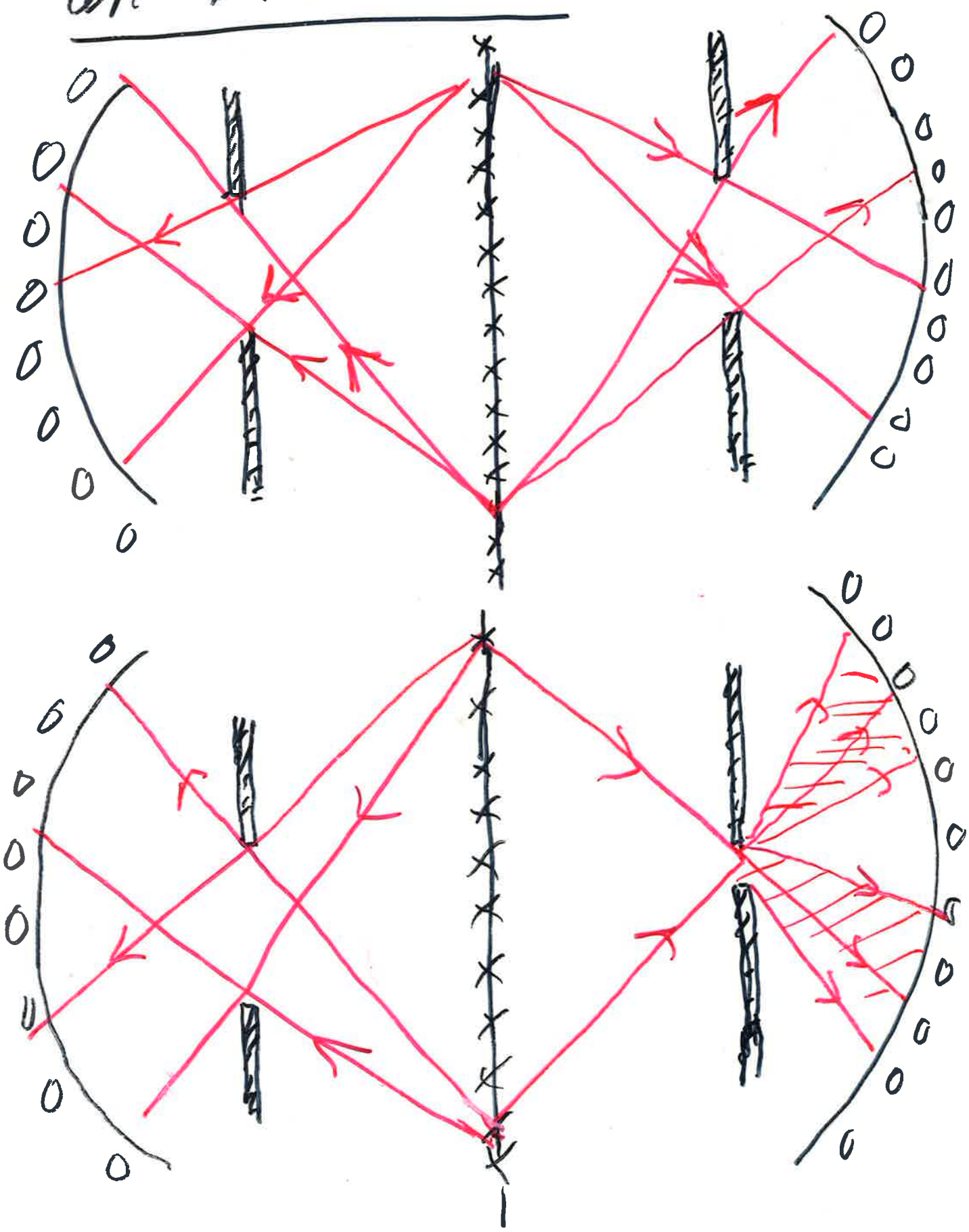
$$\langle \bar{\Psi}_t | A_1 | \bar{\Psi}_t \rangle$$

$$= \int_{-\infty}^{+\infty} \langle y_t | A_1 | y_t \rangle \, dy$$

where $|y_t\rangle$ is time-evolved state at time t which starts at $t=0$ as an eigenstate $|y\rangle$ of position

So expectations are <u>additive</u> - <u>no interference</u>

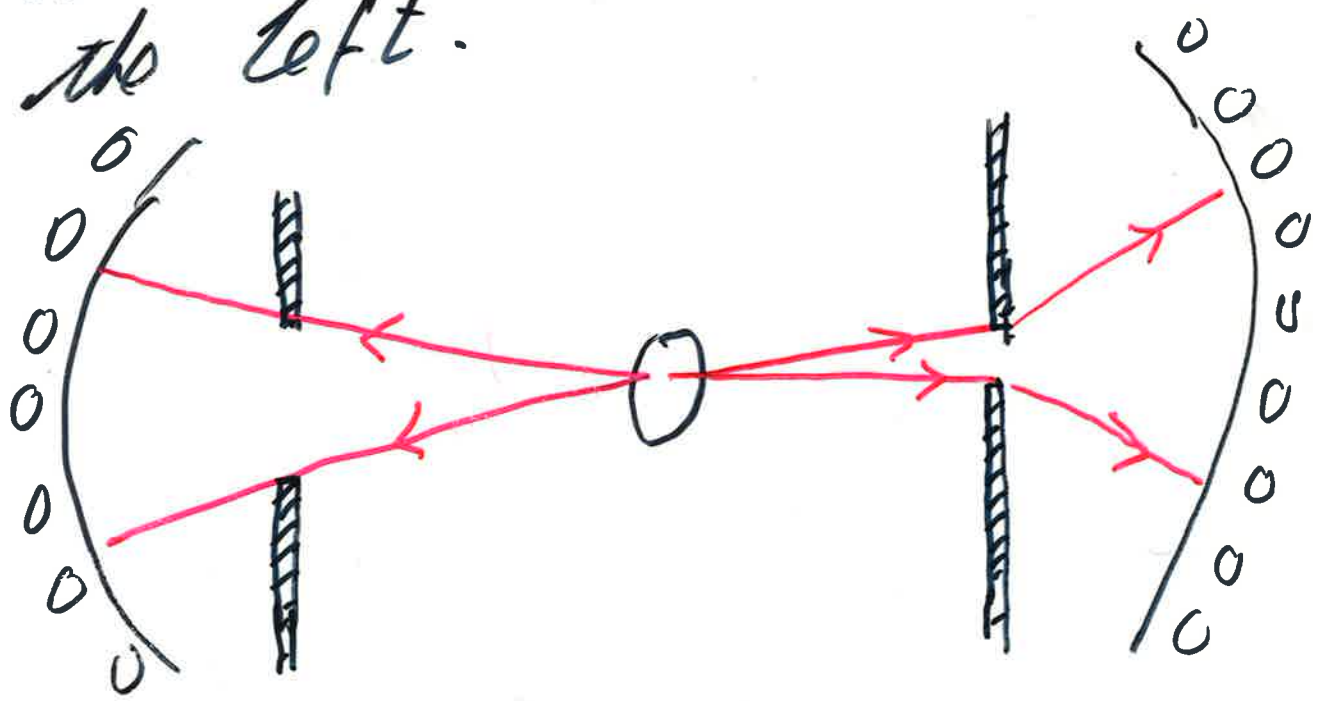
Popper's experiment with an EPR Source



Truncating the ESR Source

$$\Psi_0 = \int_{-\ell}^{+\ell} |y\rangle \otimes |y\rangle \, dy$$

But then we lose the momentum correlations, so a narrow beam on the right does not correlate with a narrow beam on the left.



General analysis of Popper's experiment

Suppose Ψ is a general 2-particle state, with one particle moving to the right and one to the left.

Measure observable A on the left, with eigenvalues a_i, and B on the right with eigenvalues b_j.

Then, since A and B commute,

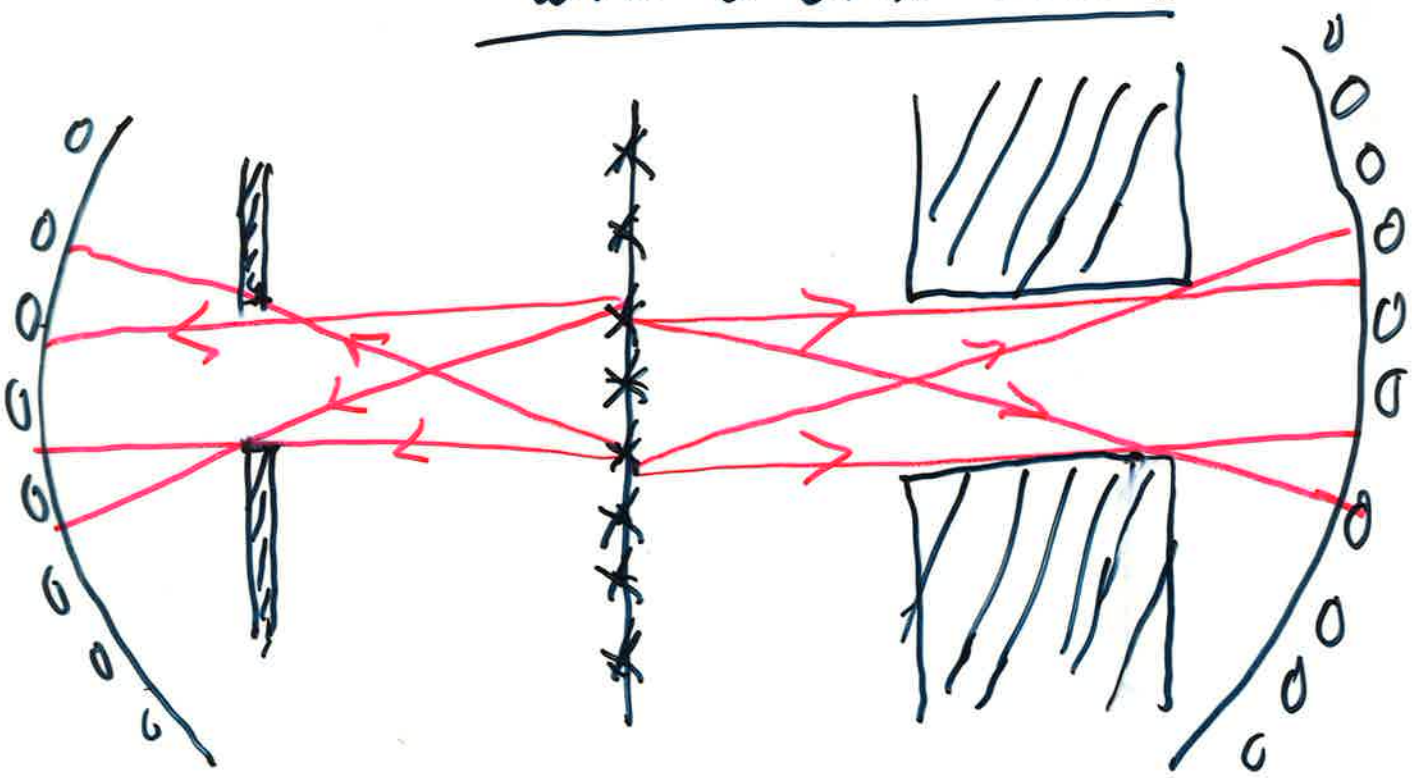
$$Prob^{\Psi}(a_i) = \sum_j Prob^{\Psi}(a_i | b_j) \times Prob^{\Psi}(b_j) \quad *$$

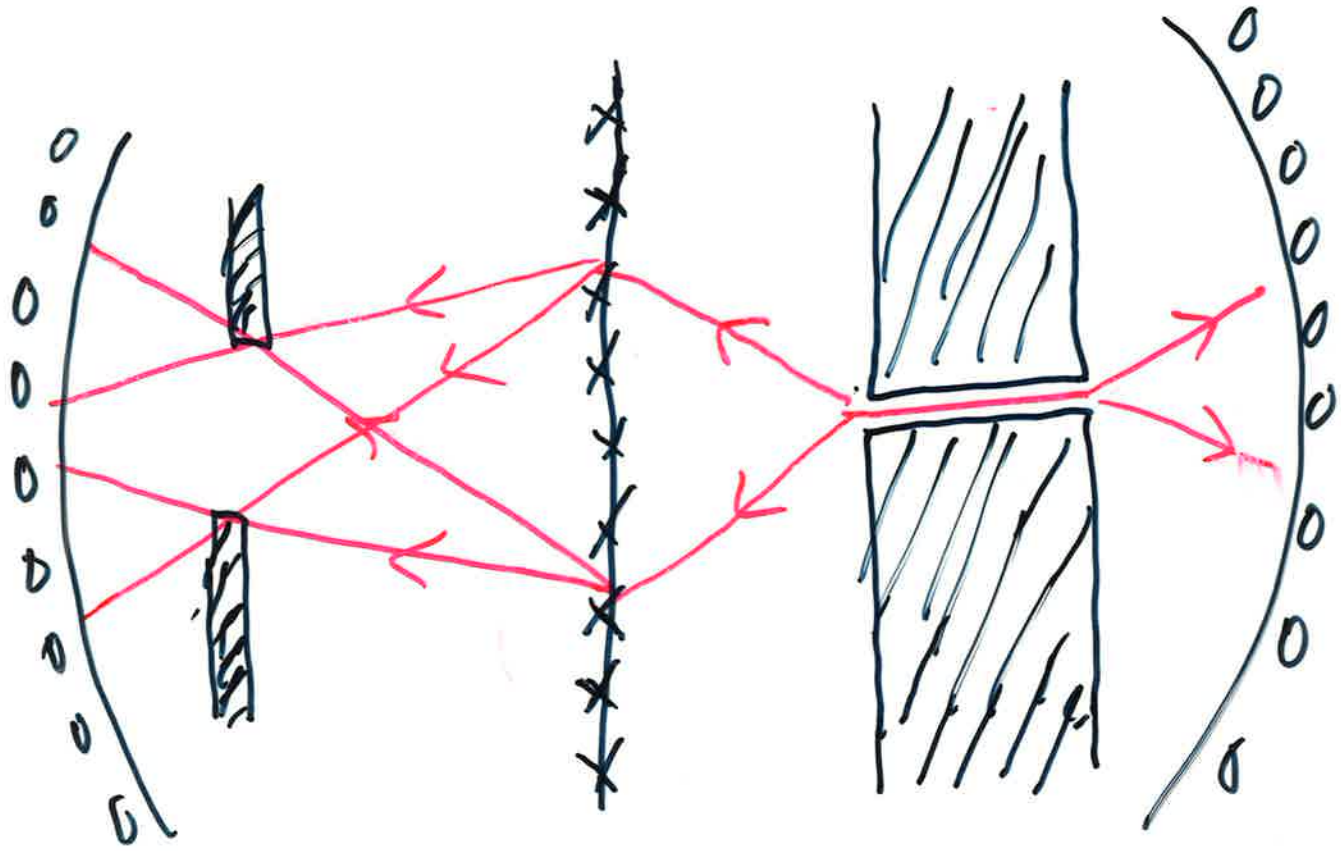
Suppose $Prob^{\Psi}(a_i) = 0$ and $Prob^{\Psi}(b_j) \neq 0$

then * implies $Prob^{\Psi}(a_i | b_j) = 0$

i.e. selecting a subensemble by conditionalizing on the right with an event that has a non-zero probability of occurring, cannot convert a zero probability for a_i into a non-zero probabilities for a_i.

Popper's Experiment with a thick screen





Time-of-flight measurement of X and P

Define $U = \frac{m(x_2 - x_1)}{t_2 - t_1}$

then measure x_1 at time t_1, and then measure position x_2 again at later time t_2, and calculate U.

U has the same probability distribution as measuring the momentum P, 'directly' at time t_2.

But can we infer that on a particular occasion, measuring U gives the same result as measuring P?

Conditional Probabilities in Quantum Mechanics

Conditional probabilities in QM are best thought of in terms of a conditional with a probabilistic consequent.

So

Prob (A/B) = p

is analysed as

B □→ (Prob(A) = p)

The Einstein - Podolsky - Rosen Experiment (1935)

2 particles emerge from a source with correlated momenta

$p_1 + p_2$ has a sharp value

and correlated positions

$x_1 - x_2$ has a sharp value

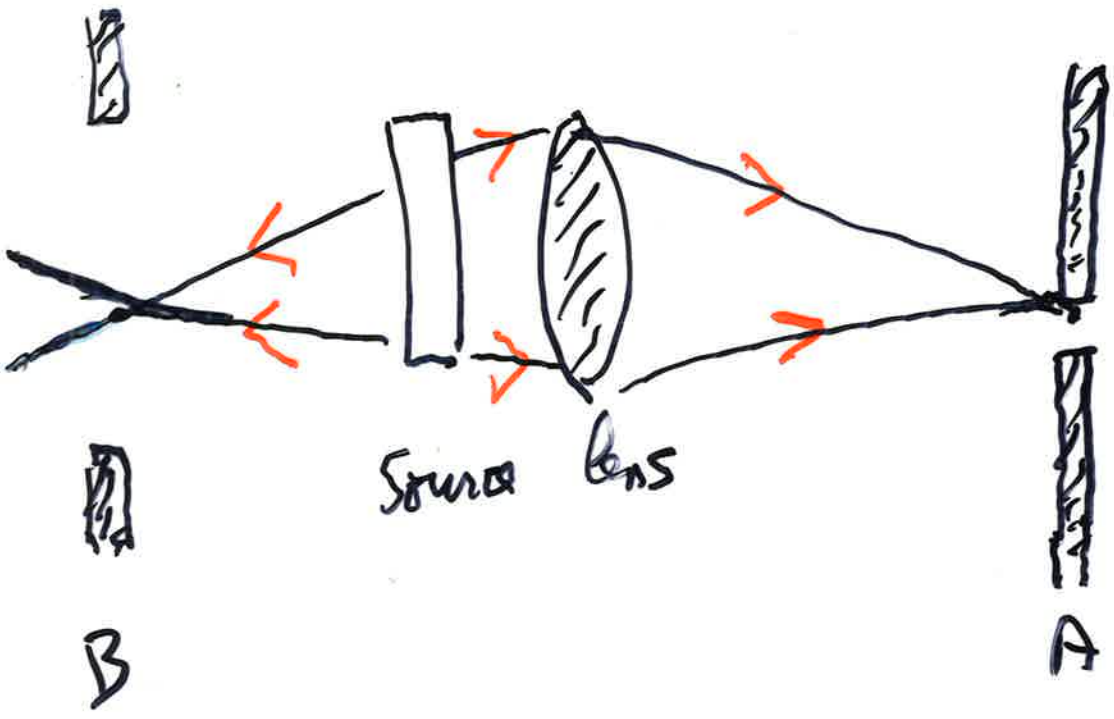
So (1) If we measure p_1, we can predict p_2, and assuming Reality this value must exist before the measurement.

(2) Similarly if we measure x_1, we can predict x_2 and again this value must exist before the measurement.

So p_2 and x_2 both have sharp values in the original initial state.

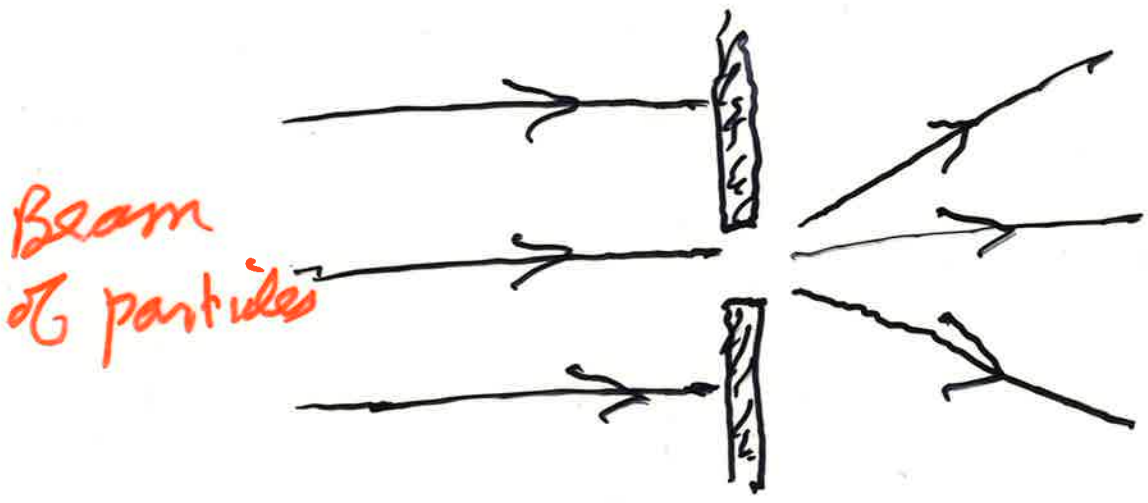
But this contradicts the Uncertainty Principle for particle 2.

The Kim - Shih Experiment (1999)

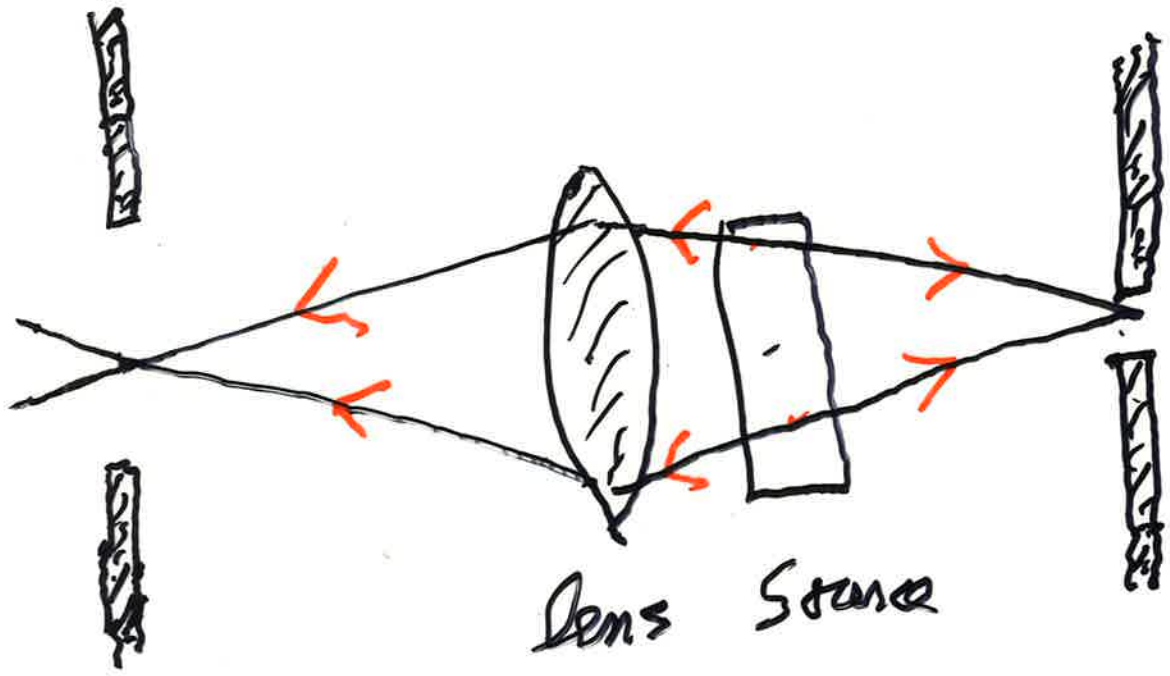


Lens forms image of narrow slit A on the wide aperture at B

The Single slit Experiment



The Kim-Shih Experiment (1999)



Lens forms image of narrow slit A on the wide aperture at B